

Gasoline Direct Injection

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Theory of GDI

Gasoline Direct Injection (GDI) is a new technology that follows Port Fuel Injection (PFI). Instead of injecting the fuel on the back side of each intake valve for each cylinder GDI sprays directly into each cylinder. GDI uses high pressure to deliver fuel at any point on the compression stroke. This allows the fuel to be considered a stratified fuel charge which means fuel/air mix is rich around the spark plug only and the remaining mixture in the cylinder is very lean. This allows for aggressive timing curves and better fuel economy. Figure 1a shows the comparison of recent innovations that help reduce fuel consumption. It shows that GDI can improve fuel economy by up to twenty five percent.

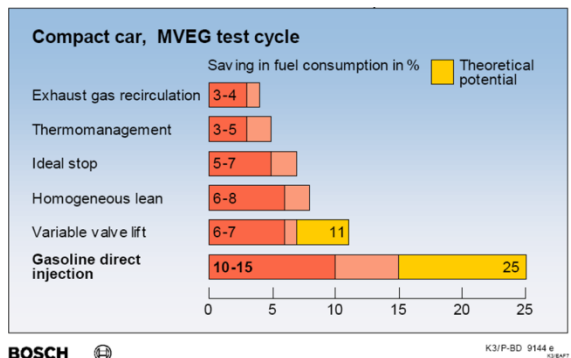


Figure 1a

GDI Components

Many manufacturers are adding GDI engines to their lineup, and each one of these engines might have one or two things different between the systems. But all GDI systems have to contain the following few base components to be considered GDI. First, they need to have a special type of injector that can inject fuel under the high pressure requirements of cylinder compression. Second, GDI systems require a high pressure fuel pump. This pump is cam shaft driven, and uses engine speed to pump and compress the incoming low pressure fuel and deliver the high pressure fuel to the injectors. Figure 1b is a picture of the Ford Eco Boost 3.5L with the GDI high-pressure fuel pump.

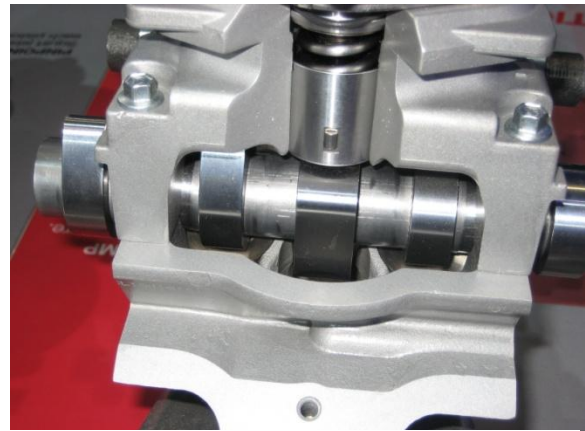


Figure 1b

One of the most important pieces of the GDI system is the PCM. A GDI compatible PCM is capable of forty percent more functions and almost twelve million more measurements than a standard PCM.

Although these are not only the parts that make up a GDI system, they are the main components that make a GDI system what it is. In addition, most systems use a combination of

turbo chargers, iridium tipped spark plugs, and different types of piston designs.

High Pressure Fuel Pump

The high-pressure fuel pump is a single piston pump that runs off of a lobe on the camshaft and uses a pressure regulator built into the pump itself. The GM SIDI high-pressure fuel pump has a FRP actuator, which controls how much fuel is allowed into the pump on the low side. Figure 2a shows a cut away of the GM SIDI high-pressure fuel pump. This cut away shows how the single piston design pump takes the low incoming fuel pressure and pressurizes it to around 2900 psi.

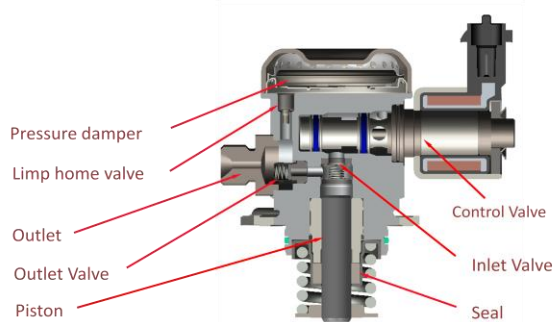


Figure 2a

Injectors

Although there are many different types and lengths of injectors, their capabilities remain the same. Most of the injectors must have the capability to spray fuel in very short bursts of less than .2ms between each injector fire. Figure 2b is a picture of a single coil fuel injector.



Delphi Multec[®] 20 GDI Fast Single Coil Fuel Injector

Figure 2b

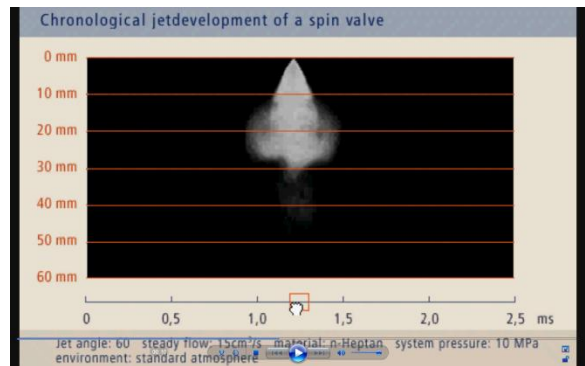


Figure 2c

Figure 2c is an image of the spray pattern of a GDI injector. This image shows that the spray pattern is in fuel development by roughly 1.25 ms, which is extremely fast compared to a standard Port Fuel system.

Other Components

Most GDI engines add a turbo charger to the system to raise the compression ratio and run a lean mixture. Due to the high fuel pressures, GDI can inject fuel even under high compression. In addition to turbo chargers, most GDI cars use multiple catalytic converters that are larger than those found on conventional fuel systems. Figure 3a shows

that there is a need for multiple cats because of the excess production of NOx. The production of the excess gas is because of the lean mixtures.

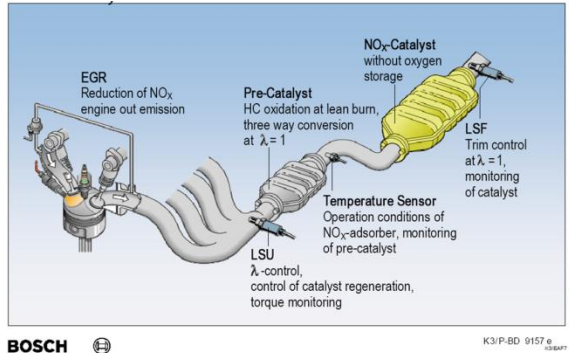


Figure 3a

Piston and Spray Design

The piston design is unique and enhances the cylinder's fuel charge. In figure 3b are three examples of how the piston design helps guide the air fuel mixture.

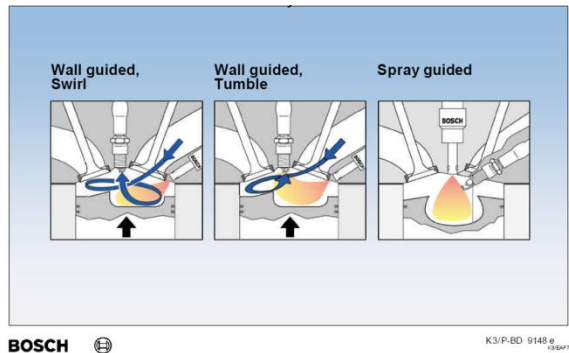


Figure 3b

As shown in Figure 3b, with all piston designs, fuel is coming from the right hand side of the cylinder (except on spray guided) and it is being injected on the combustion stroke (as shown by the arrow).

Wall guided swirl uses the piston's wall and dish to mix the air and fuel and direct it to the spark

plug. Figure 3c gives a better look into the wall guided swirl pattern.

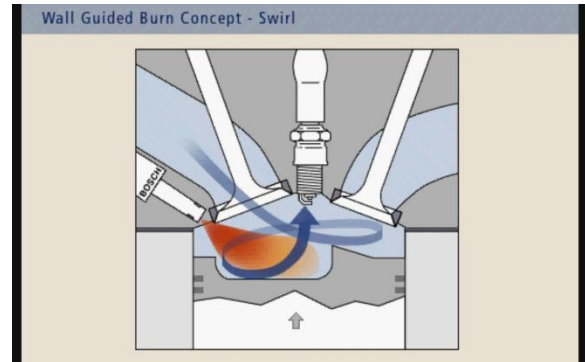


Figure 3c

With the wall guided tumble design, the air bounces off the wall and meets the fuel at the tip of the spark plug. The fuel reaches the plug because the dish design of the piston forces the fuel upward as illustrated in figure 3d.

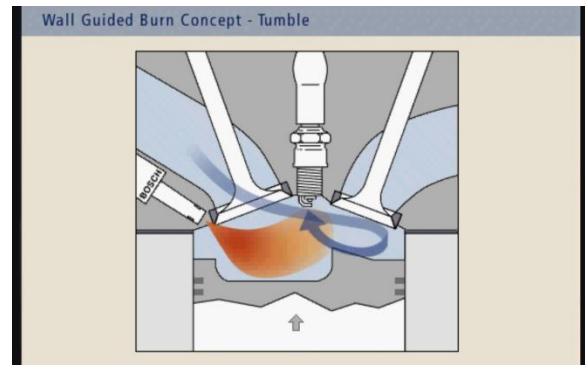


Figure 3d

The spray guided fuel design sprays fuel directly into the dish on top of the piston. The spark plug ignites the fuel going into the dish and flame propagation ignites the rest of the fuel mixture. Figure 4a is an image of the Ford Eco Boost engine's piston design. This photo shows the dished design with wall guided swirl.



Figure 4a

Fuel Pressure

GDI equipped vehicles use a standard fuel pump and fuel tank to deliver the fuel to the high pressure pump. Fuel pressure on the low side ranges from 50 to 60 psi. The high pressure pump, which is camshaft driven, produces the pressures needed to overcome the high compression pressures. The pump is capable of producing as low as 60 psi during certain modes and as much as 2900 psi at wide open throttle.

Electrical Specifications

Compared to traditional injectors, GDI injectors have lower resistances and flow more current. Amperage is typically around 10 Amps. Figure 4b shows an amperage pattern at idle. Note how quickly the pattern climbs due to the low resistance.

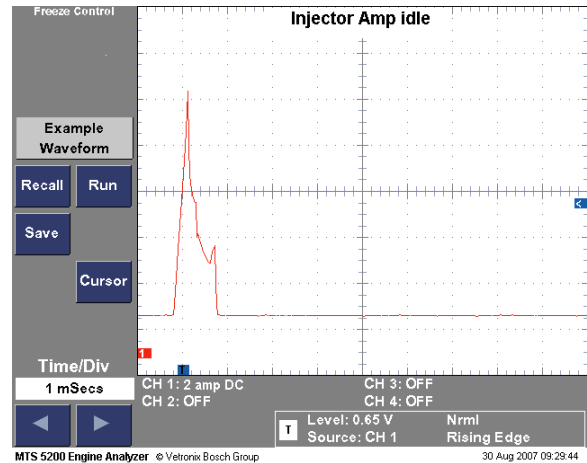


Figure 4b

An interesting thing about these injectors is the amperage waveform at wide open throttle. After the initial ramp up, the waveform indicates the injector pulling small blips of current to hold the pintle open as shown in Figure 4c.

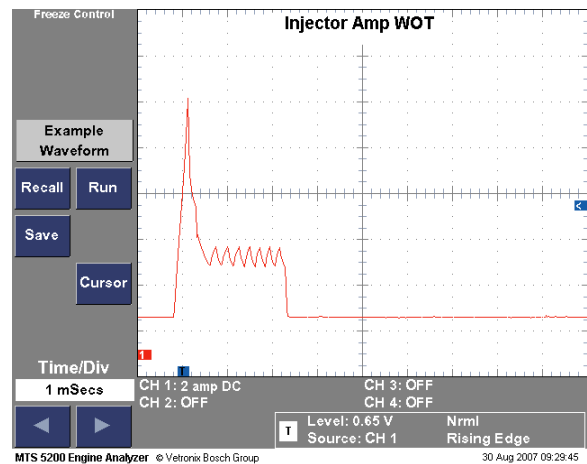


Figure 4c

The PCM amplifies the 12 volt supply by using a capacitor to create a 50-90 volt charge. Figures 5a and 5b show voltage at idle and wide open throttle respectively.

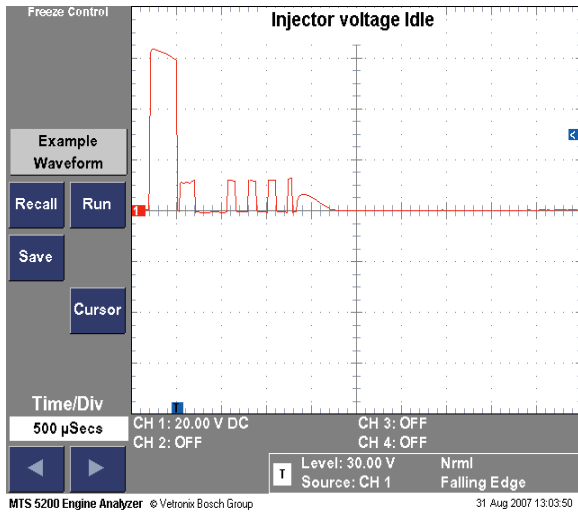


Figure 5a

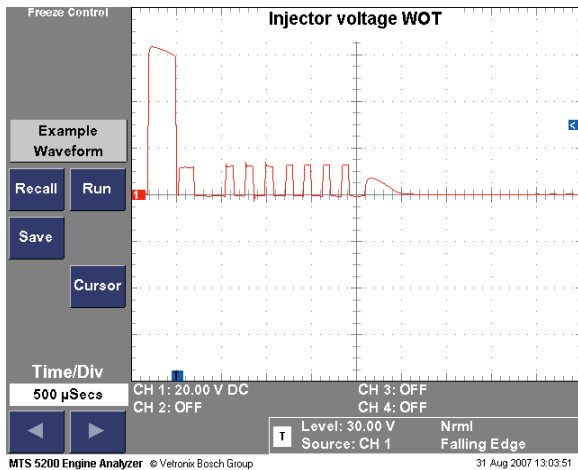


Figure 5b

Even though the injector pulse width can be as short as 4 mS, it can spray as much fuel as a conventional injector would spray in 20 mS. These quick sprays give the PCM an advantage at precisely controlling the air fuel mixture.

Mixture Modes and Strategies

Since not all manufacturers have the same GDI system, they do not all use the same modes of operation. Because of its popularity, we will look at the Bosch GDI system. There are six modes of operation

the PCM uses to precisely control the air/fuel ratio under different conditions. On a side note, the Bosch system uses a unique component called the “Charge Motion Valve.” In the intake runner, there is a PCM controlled valve that opens and closes under various conditions. When open, air is allowed to flow unrestricted to the intake valve. When closed, a portion of the runner is blocked off, causing the air to swirl and better mix with the fuel. Turbo chargers take the place of this valve in other engines. Figure 5c shows the charge motion valve in the closed position.



Figure 5c

The first mode of operation is called Homogenous mode. This mode is typically used for high speed/high torque situations. The injector sprays a single shot on the intake stroke and mixes with the air to form a 14.7:1 mixture. The charge motion valve is open to allow normal air flow.

The second mode is Stratified mode. This mode is used to achieve the leanest, most economical mixture to decrease emissions and increase fuel economy. Stratified mode is normally used during cruising/low power conditions. The throttle plate is fully opened and the charge motion valve is closed to allow

the air to flow rapidly into the cylinder. The injector sprays a single, lean shot just before combustion. Because the spray is centered around the spark plug, the fuel cannot cool on the cylinder walls and condensate.

The third mode is called Homogenous Lean mode. In this mode, the charge motion valve is still closed, and the throttle blade is controlled. This mode is used on some low power situations. The injector sprays one lean shot that mixes with the air swirl on the intake stroke.

The fourth mode is called Homogenous Stratified Mode. This is where things start to get interesting. The charge motion valve begins to close as the throttle plate begins to open. The injector actually sprays two shots: a lean shot that mixes with the air on the intake stroke, and a rich shot just before combustion. The rich mixture burns the lean mixture and decreases the amount of fuel needed for combustion. Actually, less fuel is consumed in this mode than the Homogenous mode and fewer emissions are produced than stratified mode. This mode is used mostly as a smooth transition between different modes.

One of the advantages of GDI engines is the ability to burn lean mixtures with the capability of decreasing NOx production. In the fifth mode, Homogenous Knock Protection Mode, the injector again sprays twice. The first spray is on the intake stroke (homogenous lean) and the second spray is just before combustion. The shot just before combustion in this mode varies, because it is used to adjust the Lambda value. That shot also lowers the combustion temperature, which we all know reduces NOx. This decreases the need to retard timing and, therefore, is the mode that is used under heavy engine loads.

The final mode is called Stratified Catalyst Heating Mode. The name alone should tell you what this mode is used for. That's right, heating the catalytic converter on cold startup to allow the O2 sensors to become active sooner. This is another strategy to decrease cold start emissions. The converter can actually reach temperatures of 1200-1300°F, which will also "de-sulfurize" it. The injector again sprays twice, but differently than homogenous stratified and homogenous knock. The first shot is a stratified and the second happens just AFTER combustion, which heats the exhaust leaving the cylinder.

Figure 6a shows a rough idea on when the injector sprays are timed for each mode.

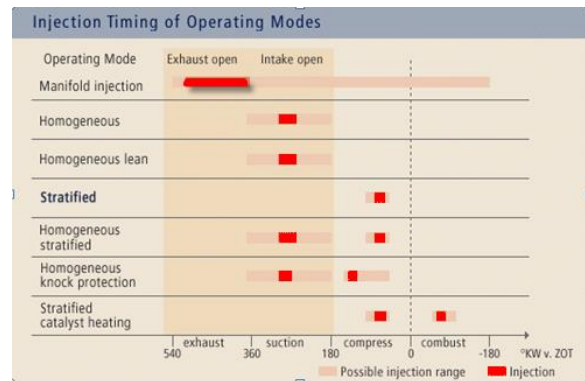


Figure 6a

Common GDI Failures

It is commonly said that if you want to thoroughly test a vehicle or component, put it in the hands of the public. Although GDI is a relatively new system, failures are becoming evident.

One of more common failures to date is that of the high pressure pump and components. The pump itself can develop an internal fault and bleed-off pressure. The

seals for the pump can leak, which causes fuel to leak into the crankcase. One of the more catastrophic failures is the breakdown of the camshaft lobe or cam follower. On the high pressure pump, there is a spring-loaded shaft that rides on the camshaft lobe through a cam follower. The lobe can become “flat-spotted” and the follower can become scored and worn. Figure 7a shows two cam followers. The one on the left is badly worn and the one on the right is a new one.



Figure 7a

In figure 7b, you can see that the high pressure fuel pump spring broke through the retaining cap and the cam follower.



Figure 7b

The camshaft itself can be damaged as well. As you can see, a failure of any of these

components can be quite costly. Figure 7c shows a worn camshaft lobe.

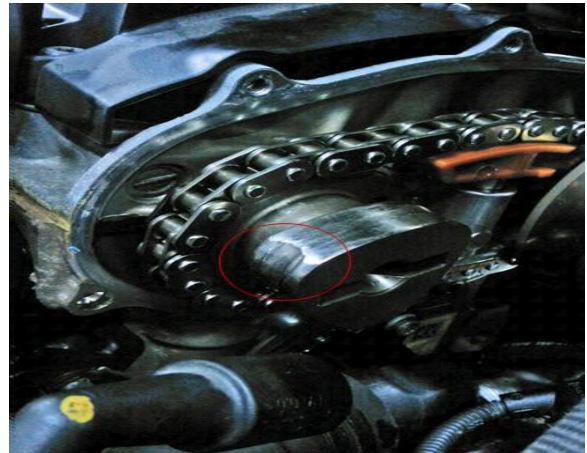


Figure 7c

Manufacturers of the GDI systems have created new codes to aid in diagnosing faults, especially in the high pressure fuel circuit. These codes and a brief description are listed at the end of this report.

Unfortunately, due to the lack of time that GDI has been out on the road, there is not a lot of opportunity to diagnose and manipulate the systems. For the most part, these vehicles will be returning to the dealerships for repair for the next several years. But this does not mean that we, as technicians, cannot begin to familiarize with the system.

Information and pictures provided by The Bosch Group, General Motors, and Tim Janello.

DTC	Description	Notes
P0087	Fuel Rail/System Pressure –Too Low	The actual fuel pressure is more than 1500 kPa below the desired fuel pressure.
P0088	Fuel Rail Pressure (FRP) Too High	The actual fuel pressure is more than 2000 kPa above the desired fuel pressure.
P0089	Fuel Pressure Regulator Performance	The fuel pressure adjustment is more than +3,000 kPa or less than -3,000 kPa.
P0090	Fuel Pressure Regulator Control Circuit	The fuel pressure regulator voltage is between 1-4.5 volts with the fuel pressure regulator commanded OFF. Or The above condition is present for more than 4 seconds.
P0091	Fuel Pressure Regulator 1Control Circuit Low	The fuel pressure regulator voltage is less than 1 volt with the fuel pressure regulator commanded OFF. Or The above condition is present for more than 4 seconds.
P0092	Fuel Pressure Regulator 1Control Circuit High	The fuel pressure regulator voltage is more than 4.5 volts with the fuel pressure regulator commanded ON. Or The above condition is present for more than 4 seconds
P0261	Injector 1 Control Circuit Low Voltage	
P0262	Injector 1 Control Circuit High Voltage	
P0264	Injector 2 Control Circuit Low Voltage	
P0265	Injector 2 Control Circuit High Voltage	
P0267	Injector 3 Control Circuit Low Voltage	
P0268	Injector 3 Control Circuit High Voltage	
P0270	Injector 4 Control Circuit Low Voltage	
P0271	Injector 4 Control Circuit High Voltage	
P2146	Fuel Injector Group Cylinder 1 Supply Voltage Circuit/Open	
P2149	Fuel Injector Group Cylinder 2 Supply Voltage Circuit/Open	
P2152	Fuel Injector Group Cylinder 3 Supply Voltage Circuit/Open	
P2155	Fuel Injector Group Cylinder 4 Supply Voltage Circuit/Open	

A list of GDI specific DTS's